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Technical Report

DEEP-OCEAN BIODETERIORATION OF
MATERIALS — PART IV. ONE YEAR
AT 6,800 FEET

June 1966

NAVAL FACILITIES ENGINEERING COMMAND



U. S. NAVAL CIVIL ENGINEERING LABORATORY
Port Hueneme, California

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DEEP-OCEAN BIODETERIORATION OF MATERIALS — PART IV. ONE YEAR AT 6,800 FEET

Technical Report R-456

Y-R011-01-01-042

by

James S. Muraoka

ABSTRACT

As Part IV of a series of reports on the biological deterioration of materials in the deep ocean, this report covers the data obtained after exposing metallic and nonmetallic specimens for 13 months on the floor of the Pacific Ocean at a depth of 6,800 feet (Test Site I). The specimens were attached to a Submersible Test Unit that was retrieved in February 1965. Preliminary examination of the specimens was made aboard ship, and the final examination, tests, and analyses were performed at the Naval Civil Engineering Laboratory.

On recovery, most of the plastic materials and all of the rope specimens were covered with bacterial slime. Cotton and manila rope specimens were severely deteriorated by marine microorganisms. Wooden test panels, plastics, and Manila ropes were attacked by molluscan borers. Glass, metals, natural and butyl rubber, and certain plastic materials were not adversely affected.

The results of breaking-strength tests on ropes, weight loss measurements of wood panels, moisture absorption tests on plastics, and insulation resistance and voltage breakdown tests on electrical insulating materials are presented.

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The Laboratory invites comment on this report, particularly on the results obtained by those who have applied the information.

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PREFACE

The U. S. Naval Civil Engineering Laboratory is conducting a research program to determine the effects of the deep-ocean environment on materials. This research will be of great value in establishing the best materials to be used in deep-ocean construction in the Navy's conquest of "inner space."

A Submersible Test Unit (STU) was designed on which many test specimens can be mounted. The STU can be lowered to the ocean bottom and left for long periods of exposure. This report deals with STU I-4, in place for 13 months at a depth of 6,800 feet. The test site is about 81 nautical miles southwest of Port Hueneme, California.

INTRODUCTION

As part of a research program to determine the effects of the deep-ocean environment on various materials, the U. S. Naval Civil Engineering Laboratory (NCEL) in March 1962 placed the first of a series of Submersible Test Units, designated STU 1-1, on the ocean floor in 5,300 feet of water at Test Site I off the coast of California (Figure 1). Since then additional STU's were placed on the sea floor and these are listed in Table 1 with pertinent information about each STU.

STU 1-4 was recovered in July 1965 after 13 months on the sea floor in 6,800 feet of water. A sketch of the STU 1-4 system as installed is shown in Figure 2. The STU was loaded with 1,852 specimens of 567 materials (Figure 3). The majority of these materials were metal and metal alloys for the study of corrosion. For biodeterioration study, nonmetallic materials, such as woods, ropes, and plastics, were assembled in two aluminum racks (bio-racks) and then attached to the side of the STU for exposure in the deep-ocean environment.

This report presents the materials and the methods used for attracting, collecting, and evaluating deep-sea fouling and boring organisms and the results of field and laboratory investigations of the materials recovered from STU 1-4.

RESEARCH METHODS

Oceanographic Information

Concurrently with the STU program, numerous oceanographic and biological data-collecting cruises to the STU sites have been conducted. These have produced information about the environmental parameters, such as salinity, temperature, oxygen content, and biological activity. Such information is essential in evaluating changes in the materials exposed on the ocean floor, especially the corrosion of metals. The environment for Test Site I (6,800-foot depth) is presented in Table 2 and in an unpublished report.*

Test Site I was selected because the area provides a nominal 6,000-foot depth reasonably representative of the open-sea conditions in the eastern part of the Pacific Ocean. It is located about 80 nautical miles southwest of Port Hueneme, California.

* U. S. Naval Civil Engineering Laboratory. Oceanographic data. No author. Port Hueneme, Calif. In preparation.

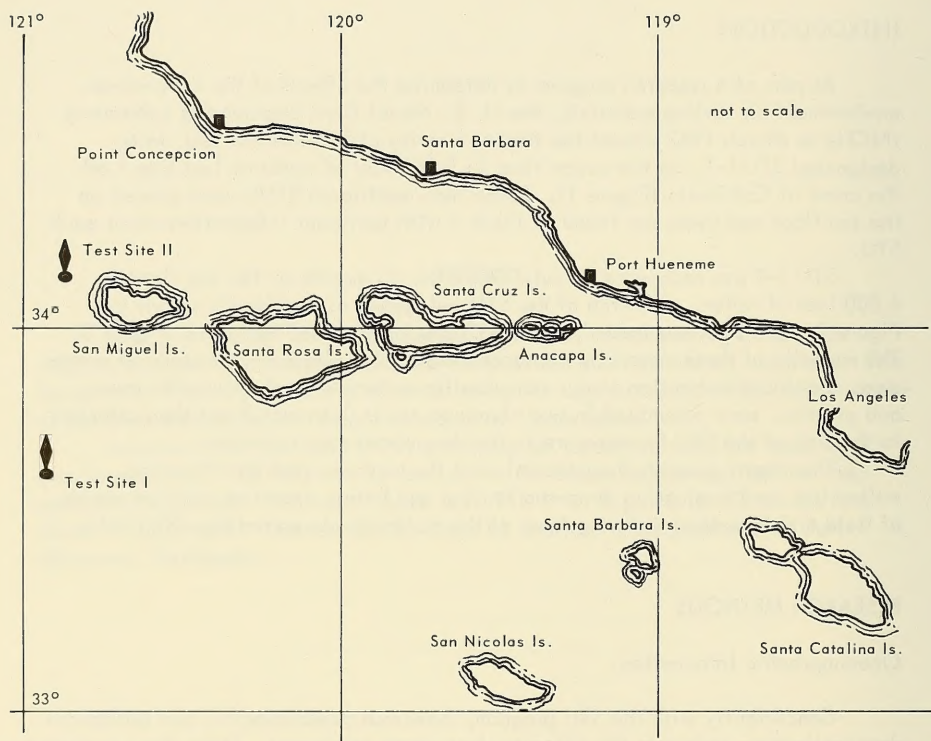


Figure 1. Test Site I (nominal depth of 6,000 feet) and Test Site II (nominal depth of 2,500 feet).

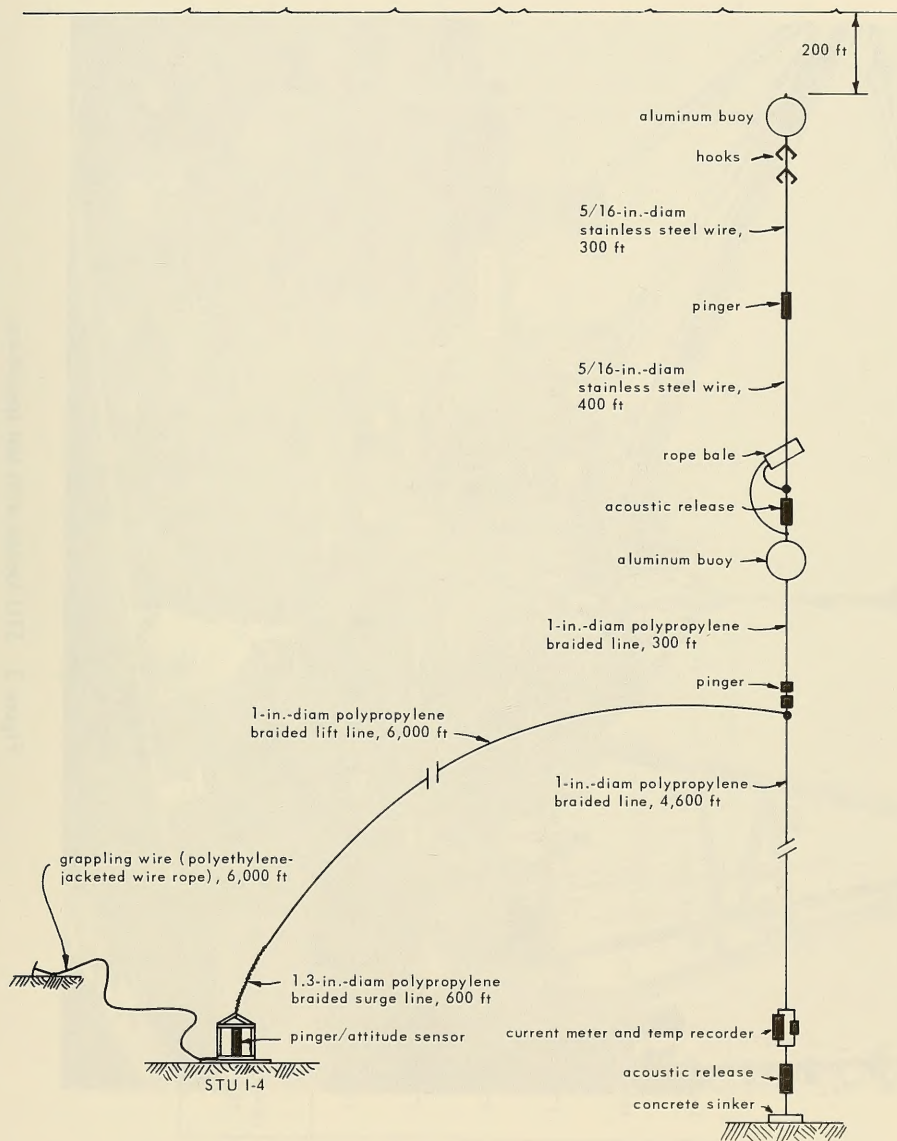


Figure 2. STU I-4 complex as designed.

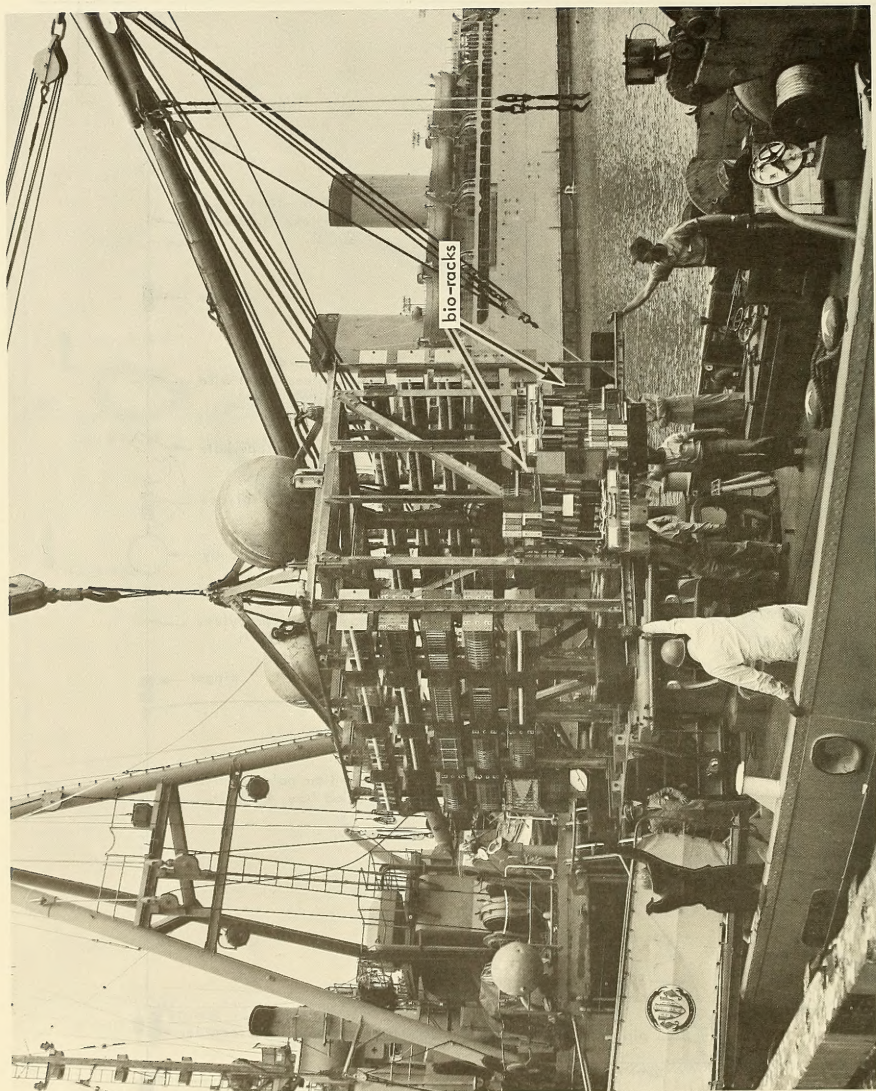


Figure 3. STU loaded with test specimens.

Table 1. STU Emplacement and Recovery Program to Date

STU Number	Test Site	Depth (ft)	Location	Date Emplaced	Date Recovered	Exposed Period (mo)	Number of Materials	Number of Specimens	Weight in Air of STU With Materials Before Exposure (lb)	Results Published (Reference Number)
I-1	I	5,300	33°46'N 120°37'W	March 1962	February 1965	35	396	1,282	7,000	1
I-2	I	5,640	33°44'N 120°45'W	October 1963	October 1965	24	429	1,521	5,600	In preparation
I-3	I	5,640	33°44'N 120°45'W	October 1963	February 1964	4	398	1,367	5,200	2
I-4	I	6,800	33°46'N 120°46'W	June 1964	July 1965	13	567	1,852	6,710	This report
II-1	II	2,340	34°06'N 120°42'W	June 1964	December 1964	6	603	2,385	7,350	3
II-2	II	2,340	34°06'N 120°42'W	April 1965	May 1966	13	811	2,588	8,750	—

Table 2. Environment at Test Site I

Environmental Factors	Surface Water	Test Site I
Depth, ft	—	6,800
Water temperature, °C	13.0	2.1
Dissolved oxygen content, ml/l	5.6	1.71
Salinity, ‰ (ppt)	33.6	34.52
pH	7.9	7.84
Hydrostatic pressure, psi	—	3,000
Current, knots	—	—
Sediment	—	Green mud containing glauconite, Foraminifera tests, quartz, etc.

Biological Activity

When NCEL first decided to place STU I-1 on the sea floor at Test Site I in March 1962, neither the topography of the sea floor nor the kind of deep-sea creatures that would be encountered were known. In order to obtain some information, a deep-sea camera was lowered from the stern of a vessel while at the same time STU I-1 was being lowered to the ocean floor from the bow of the vessel. Numerous photographs were taken of the sea floor close to where STU I-1 was placed.

The photographs revealed that the topography of the sea floor in the vicinity of Test Site I was generally flat except for small mounds built by mud-dwelling animals. The presence of these mounds indicates that there is considerable biological activity in the area. While the photographs of the sea floor were being taken, a 5- to 6-foot-long shark-like fish with a large dorsal fin came into view of the camera and was photographed apparently drifting near the sea floor in 5,300 feet of water (Figure 4).

Rock Samples

Rock specimens were desired from Test Site I so that the fouling organisms attached to the rocks could be studied; these organisms could be expected to attach themselves to other materials as well. A 10-inch-diameter, 36-inch-long steel pipe

with retaining rods welded across its lower end was employed for collecting rocks from the ocean floor. The pipe dredge was lowered to the ocean floor from an oceanographic vessel, USNS Davis, and the area was dredged for rock specimens. Several passes were made across the area of Test Site I at a depth of 6,000 feet, and rocks of various sizes were collected. Various organisms were attached to the collected rock specimens (Figure 5), and these are listed in Table 3.

Several rocks had deep holes bored by pholads; neither live pholads nor their empty shells were found, so it is not known whether these rock borers are active at this depth. There was a deposit (as great as 1/4 inch thick) of manganese oxide on the rock specimens. Chemical and instrumental analyses of these deposits were made by U. S. Bureau of Mines, Tiburon, California. The results of these analyses are presented in Table 4. Further information on the manganese deposits on the floor of the Pacific is given in Reference 4. It is believed that bacteria play a major role in the formation of nodules, for it is reported in Reference 5 that 36 pure bacterial species were found and isolated from inside surface-sterilized manganese nodules.

Sediment Samples

Marine bacteria are among the major biological agents in the deterioration and fouling of various materials submerged in the sea. To determine the type and activity of bacteria in the deep sea, sediment samples were obtained and analyzed in the laboratory by means of standard microbiological methods. Samples were also obtained to determine the type of marine animals found in the sediment.

Table 3. Fouling Organisms on Rocks From 6,000-Foot Depth

Organisms	Remarks
Bryozoa	Six or more different species of encrusting and erect forms; one encrusting form covered about 1 square inch of rock surface
Foraminifera	Many different species
Glass sponges	Several different deep-sea species
Serpulid worm tubes	Numerous large and small; the longest was over 4 inches
Brittle stars	One found in a pholad hole
Chiton.	One 1/2-inch long



Figure 4. A 5- to 6-foot-long shark-like fish with a large dorsal fin, on the sea floor in 5,300 feet of water. (Courtesy of Carl Shipek of the U. S. Navy Electronics Laboratory.)

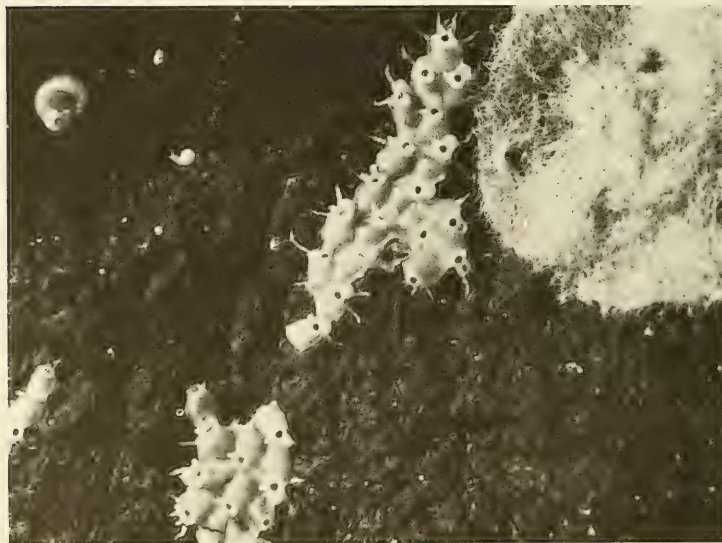


Figure 5. Photomicrograph of colonial (encrusting) bryozoa, deep-sea glass sponge, Foraminifera, and worm tubes on a rock surface (magnified).

Table 4. Chemical and Instrumental Analyses of Manganese Incrustation

The samples were obtained about 30 miles south of San Miguel Island, 33° 46' N and 120° 49' W, at a depth between 5,000 and 6,000 feet.

Element	Sample No. 1 (%)	Sample No. 2 (%)
Ca	0.64	0.67
Mg	1.10	0.99
Cr	0.010	0.013
Mn	12.4	12.5
Fe	16.42	19.08
Ni	0.26	0.24
Cu	0.05	0.07
Pb	0.13	0.22
Zn	0.07	0.05
Sr	0.02	0.03
Co	0.05	0.05
Ba	0.05	0.04
Mo	0.35	0.42
K	0.56	0.44
Na	1.03	1.20
Si	10.1	8.9
Ti	0.74	0.78
Al	3.67	2.61
P	0.38	0.44
S	0.09	0.14
H ₁ /	0.8	1.1
O	46.0	45.0
Total	95.0	95.0

1/ Calculated from percent water obtained by drying at 110°C.

The following samplers, previously described in Reference 2, were used to collect sediment samples from the deep sea:

1. A gravity core sampler, which takes cores up to 4 feet long.
2. NCEL's scoop-type sampler, which collects about 225 cubic inches of sediment from the soft bottom of the ocean.
3. A ZoBell bacteriological sampler with a sterile sampling unit (modified in order to collect a mixture of seawater and sediment at the seawater - sediment interface).

The results of the bacteriological analysis of the sediment samples are presented in Tables 5, 6, and 7.

Table 5. Aerobic and Anaerobic Bacteria in Core Samples of Sediment

Sample No.	Depth (ft)	Depth of Sample Below Ocean Floor (in.)	Aerobes (per gram of wet sediment)	Anaerobes (per gram of wet sediment)	Presence (+) or Absence (-) of Sulfate Reducers
C162	5,300	0 - 1	12,000	600	+
		3 - 3.5	10	200	+
		6 - 6.5	0	600	+
		12 - 12.5	0	200	-
		24 - 24.5	0	50	+
		36 - 36.5	0	0	-
C163	5,300	0 - 1	6,000	5,000	+
C262	5,640	0 - 1	2,000	300	+
		1 - 1.5	1,000	500	+
		2.5 - 3.0	30	30	+
C362	5,640	0 - 1	8,000	5,000	+
		3 - 3.5	60	60	+
		6 - 6.5	0	0	+
		12 - 12.5	0	0	+
		18 - 18.5	0	0	+

Table 6. Aerobic Bacteria in Scoop Samples of Sediment

Sulfate-reducing bacteria present in all these samples.

Sample No.	Depth (ft)	Aerobes (per gram of wet sediment)
M662	5,300	25,000
M163	5,640	30,000

Table 7. Aerobic and Anaerobic Bacteria in Sediment Obtained With a ZoBell Bacteriological Sampler

Sulfate-reducing bacteria present in all these samples.

Sample No.	Depth (ft)	Aerobes (per gram of wet sediment)	Anaerobes (per gram of wet sediment)
Z462a	5,300	300,000	not tested
Z462b	5,300	500,000	not tested
Z5a62	5,300	1,500,000	500,000
Z5b62	5,300	1,870,000	500,000
Z5d62	5,300	1,700,000	600,000
Z11a63	5,640	1,500,000	600,000
Z11b63	5,640	2,000,000	600,000

The number of aerobic, anaerobic, and sulfate-reducing marine bacteria was determined in the laboratory on nutrient agar plates and in test tubes. Because of the different nutritional requirements of marine bacteria and the limitation in the enumeration procedure employed in this study, only a small percentage of the marine bacterial population may have been determined from the bottom samples. The following media were used for culturing marine microorganisms:

1. The nutrient medium used with pour plates for determining the general aerobic bacterial population consisted of⁹

Bacto-peptone	5.0 gm
Ferric phosphate	0.1 gm
Yeast extract	1.0 gm
Seawater (aged)	1,000 ml
Bacto-agar	20 gm
pH	7.5

2. The general anaerobic bacterial population was determined by using the Fisher-Spray anaerobic culture dishes with the above medium, which was treated with sodium formaldehyde sulfoxylate (1.0 gm/l) to lower the redox potential and with resazurin (0.001 gm/l) to serve as an indicator of anaerobiosis.⁹

3. The nutrient medium for determining the presence of sulfate-reducing bacteria consisted of⁹

Potassium phosphate dibasic	0.2 gm
Magnesium sulfate hydrated	0.2 gm
Sodium sulfite	0.1 gm
Ferrous ammonium sulfate	0.1 gm
Calcium lactate	3.5 gm
Ascorbic acid	0.1 gm
Bacto-peptone	1.0 gm
Yeast extract	1.0 gm
Seawater (aged)	1,000 ml
pH	7.5

For this study, agar was deleted from the above medium. The medium was placed in test tubes with screw caps and sterilized. The screw caps were tightened when the medium was still warm to exclude atmospheric oxygen. Small samples of bottom sediment from various depths were placed in these test tubes and incubated for several days at 15°C.

The sediment samples obtained with a scoop sampler were washed through a plastic screen to collect mud-dwelling organisms. The animals were bottled and preserved in a 5% glycerol-alcohol solution aboard ship for laboratory analysis.

A variety of animals was found in these sediment samples. Annelid worms were the most abundant marine organisms collected in the vicinity of Test Site 1. Other mud dwellers collected were nemertean (round worms), holothurian (sea cucumbers), amphipods, molluscans, and Foraminifera tests. The Foraminifera tests found in the sediment samples have been classified and are reported in Reference 2.

Test Materials

For evaluating deep-sea biological effects on nonmetallic specimens, two bio-racks were attached to the STU. Each rack held several 3-foot-long plastic rods and tubes and a 12×30×1/8-inch laminated phenolic plastic sheet (Figure 6). Numerous smaller test specimens were attached to the plastic sheet; one sheet was secured to the upper section of a bio-rack, and an identical sheet was secured to the bottom section. In order to expose the test materials to biodeterioration in mud as well as in water, the two racks were attached to the STU so that the lower portions would be either exposed near or buried in the bottom sediment and the upper portions would be exposed to seawater 3 to 4 feet above the mud line.

The bio-rack test specimens are listed in the Appendix. The 2×6×1/2-inch wooden panels were cut from sound lumber, and the surfaces were cleaned with alcohol and then covered with plastic to avoid contamination. The plastic covers were removed just before the test specimens were submerged. The wooden panels were employed to collect specimens of any deep-sea fungi and marine borers which may have been present on the ocean floor.

The sections of the 3-foot-long plastic rods, tubes, and pipe, and the rubber tubes were treated in different ways. One section of each specimen was roughened, a second section was wrapped in burlap, a third section was taped with plastic and rubber electrical tape, and a fourth section was left smooth. The various wrappings provided a favorable foothold for the attachment and growth of deep-sea fouling and boring organisms. A large piece of untreated fir wood was fitted around both ends of each specimen to act as bait to attract and lead borers into direct contact with the specimen materials.

Four different kinds of rope, such as synthetic plastic fiber rope (nylon and polypropylene) and natural fiber rope (cotton and Manila), were placed on the bio-racks. Electrical cables covered with rubber or plastic insulation of various thicknesses were also placed on the racks. A small piece of pine wood was fitted around each cable specimen to act as bait for marine borers. Another group of electrical conductors placed on the bio-racks consisted of 0.015-inch-thick insulation over a No. 16 tin-coated copper wire. The materials used in the formulation of the insulation are presented in Table 8. The wire specimens were 15 inches long; some were stressed (coiled) and some were nonstressed (straight). Stress was applied by coiling a 15-inch specimen lightly around a 1/4-inch-diameter glass rod and then removing the rod. Both ends of each specimen were sealed with two coats of

rubber cement. The specimens were positioned so that one set of ropes and electrical cables would be buried in the sediment (in which bacteria are ordinarily most active) and an identical set would be exposed about 3 feet above the sediment.

Table 8. Materials Used in the Formulation of Insulating Materials Tested

Test Specimen	Plasticizer	Filler	Antioxidant
Polyethylene (standard polyethylene insulation)	—	—	—
Polyvinyl chloride	—	—	—
Government rubber styrene (styrene butadiene rubber)	Cumarone-indene resin and micro-crystalline wax	Hard clay and water-ground whiting	Polymerized trimethyl dihydroquinoline
Silicone rubber	—	—	—
Neoprene (Type W)	Light process oil and petroleum	Hard clay	4, 4 thiobis (6-tert-butyl m-creosol)

Metal test specimens were also placed on the STU, but materials containing antifouling paints or other toxic substances were excluded from exposure aboard the STU. The current velocity at a depth of 2,340 feet (about 0.3 knot) was not great enough to carry away any water-soluble toxic substance which might alter the natural biological fauna found in the immediate vicinity of the STU.

RESULTS

Recovery of Test Materials

As soon as the recovered STU was placed on the deck of the ship, the test panels were examined and any attached organisms were photographed. The animals were then carefully lifted from the test specimens and preserved in a 5% glycerol-alcohol solution for further examination and analysis in the laboratory.

As soon as the STU was secured to the deck, the bio-racks attached to the side of the STU (Figure 7) were disassembled. The individual test specimens were placed in plastic bags for later examinations, tests, and evaluation in the laboratory.

The wooden panels, riddled with marine borers, were soaked in an alcohol solution to prevent decay and were placed in plastic bags. The wooden panels used for fungi determination were placed directly into sterile plastic bags, sealed, and stored in the ship's refrigerator. Rope specimens for the isolation of marine micro-organisms were also placed in sterile plastic bags and stored in a refrigerator. In order to determine moisture absorption, the 3-foot-long plastic rods and tubes and other plastic materials were placed in plastic bags and sealed to retain any moisture present in the plastics.

Marine Growth on Test Materials

Metal Panels. Generally there was very little fouling growth on the metal panels. Species of deep-sea hydroids (Figure 8), including tubularia and sponges (Figure 9), were the major attachment organisms found on test panels. Generally, moderate amounts of hydroid growth were found attached to the surface of monel and stainless steel panels, which were not covered with corrosion products. Very little or no hydroid growth was evidenced on panels of mild steel and panels of copper base alloys, which were covered with corrosion products.

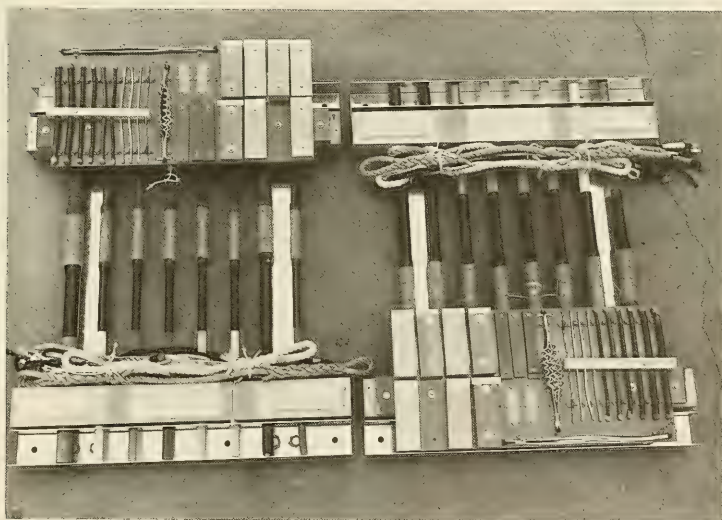


Figure 6. Various kinds of materials assembled in bio-racks before exposure.

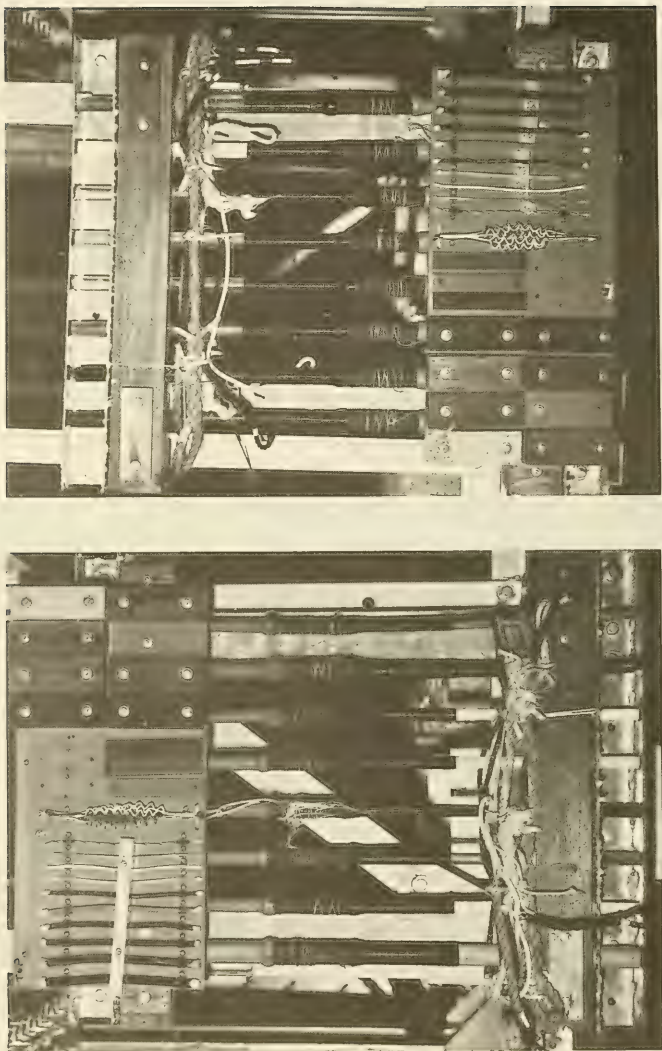


Figure 7. Materials on bio-racks attached to the side of a STU, immediately after recovery.



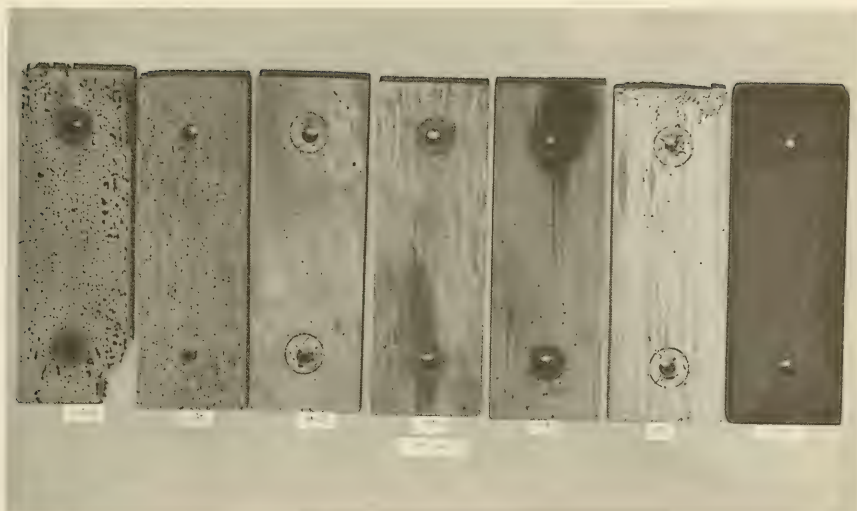
Figure 8. Hydroids on metal test specimens.



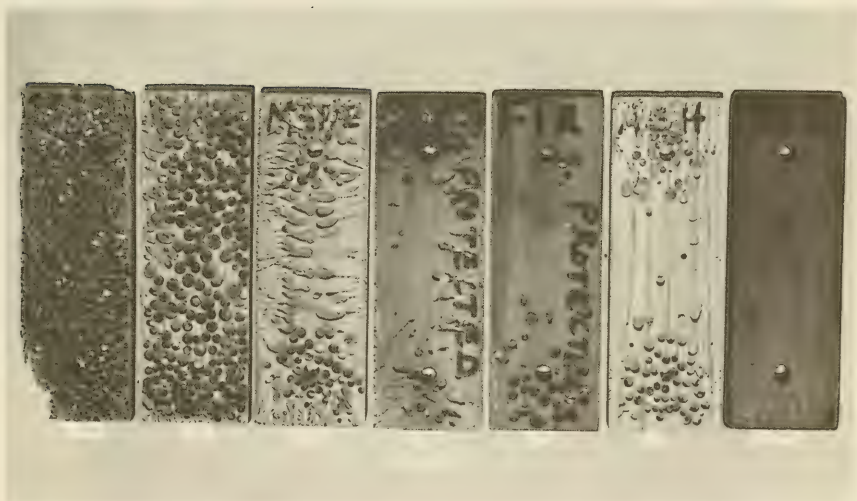
Figure 9. Species of 1/4-inch-long deep-sea sponges.

Typical fouling organisms found in shallow water, such as barnacles, tunicates, and bryozoa, were not found attached to the panels exposed at a depth of 6,800 feet.

Wooden Panels. A total of twenty-six 1/2 x 2 x 6-inch wooden test panels, which included pine, fir, ash, maple, cedar, oak, and redwood, were exposed to determine the effects of deep-sea animals on different woods. All the wooden panels were attacked by marine borers and sustained light-to-heavy damage. The severest damage was sustained by cedar and oak; moderate damage was sustained by ash, pine, fir, and maple; and light damage was sustained by redwood. The external sides of the panels exposed to seawater appeared to be relatively free of any borer attack (Figure 10a); however, when the wooden panels were removed from the phenolic laminated plastic sheet and the sides attached to the plastic sheet were examined, it became evident that the interior of the wood was completely riddled by marine borers (Figure 10b). The majority of the borer tunnels measured about 5/16 inch in diameter. The average borer tunnels in redwood measured about 1/8 inch in diameter. The loss in weight of each of these panels due to borer damage is presented in the Appendix. The surface of the phenolic plastic sheet to which the wooden panels were attached was also damaged by borer activity (Figure 11).

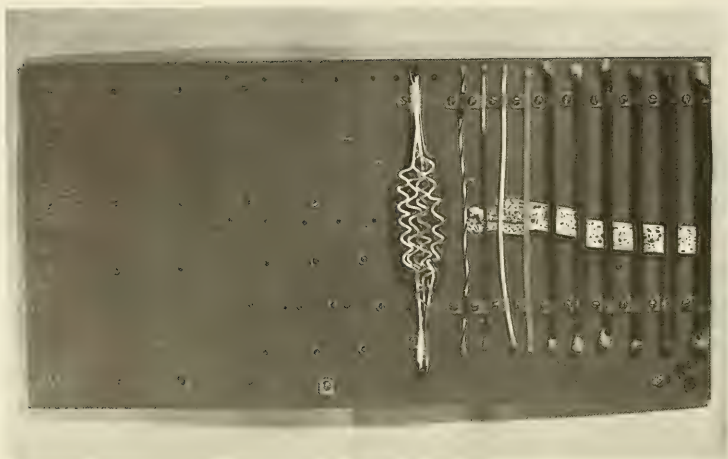


(a) External side.

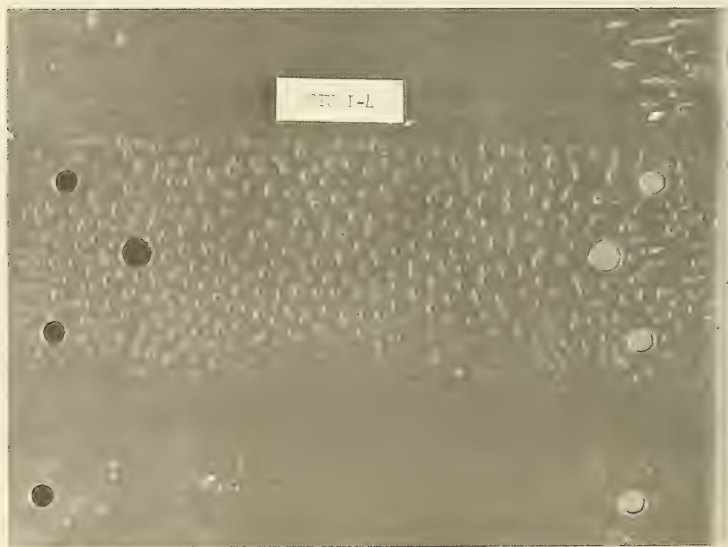


(b) Interior.

Figure 10. Wooden Panels.



(a) Full view.



(b) Closeup view of borer damage.

Figure 11. Phenolic laminated plastic sheet where wood panels were attached.

It is highly unlikely that the surfaces of the wooden panels were infested with borers during descent aboard the STU because (1) the wooden panels were dry when initially submerged and (2) the rate of descent to the sea floor was probably too rapid (100 to 150 ft/min) for any borer attachment. In order to eliminate any doubt about this matter, several panels were covered with a clean, white, bonded paper and sealed with a plastic adhesive tape to prevent any borers present near the surface from attaching themselves to the wood during descent (see Figure 6).

It is not known whether the paper coverings were detached from the wood during descent to the bottom or at the sea floor. When the panels were recovered and examined, they were also found to be riddled by borers identical to those found on uncovered test panels.

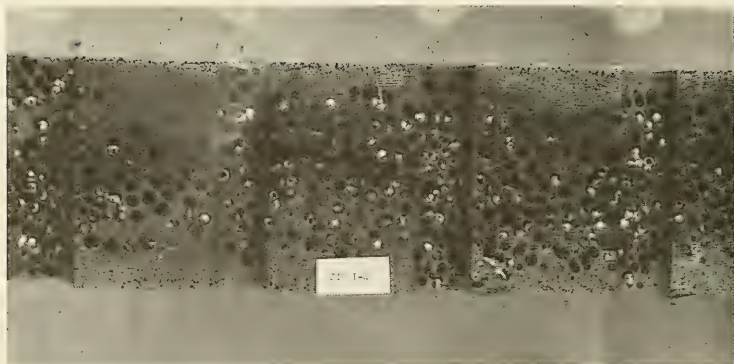
The wood panels which were exposed about 0.5 feet above the sediment layer were much more severely damaged by the borers than the set of panels exposed 3 to 4 feet above the sediment layer. This indicates that the deep-sea marine borers are very active in large numbers immediately above the sediment layer and their number tends to decrease in seawater as the distance from the sediment layer increases. A similar phenomenon has been reported in Reference 10. It is possible that these borers may not be present in seawater about 25 feet above the deep-sea floor.

The greatest borer population was found in the 2x4x30-inch bait pieces (untreated fir) fitted over the plastic rods and tubes (Figure 12). Some borers, about 3/16 inch in diameter, had penetrated about 1-1/2 inches into the center of the wood from the cut end (Figure 13). Because of the deteriorated condition of the wood, the 2x4-inch bait pieces could easily be broken apart by hand (Figure 14). Numerous white deep-sea sponges (Figure 9) were found attached to the surfaces of these woods. Numerous amphipods (Figure 15) were found between the wooden layers, and over 50 of the crustaceans were found trapped inside a plastic container.

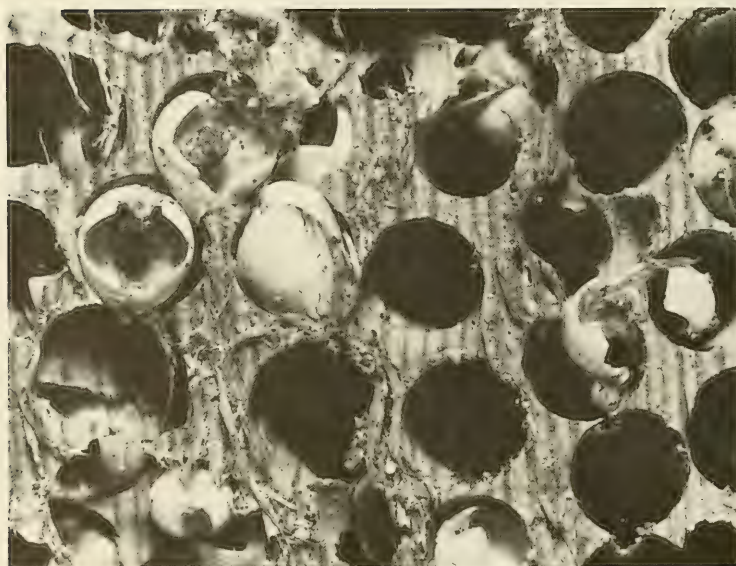
The molluscan borers (Figure 16) in these wooden bait pieces have been identified as Xylophaga washingtona Bartsch and Xylophaga duplicata Knudsen. Complete descriptions of Xylophaga washingtona and Xylophaga duplicata are presented in References 11 and 12, respectively.

Marine bacteria and fungi were also responsible for the deterioration of the wood. The surfaces of the test panels were softened by the action of bacteria and fungi. Microscopic examination of sections through the wood revealed two types of deterioration of wood cells:

1. Irregular tiny cracks and channels in the cell walls caused by bacteria. This type of deterioration was the most commonly found on the surface of the wood.
2. Wide channels in the secondary cell walls of the wood caused by higher marine fungi. This type of deterioration is known as "soft rot" and was less commonly found on the surface of the wood.



(a) Full view.



(b) Closeup view.

Figure 12. A 2×4×30-inch wooden bait piece riddled by borers.

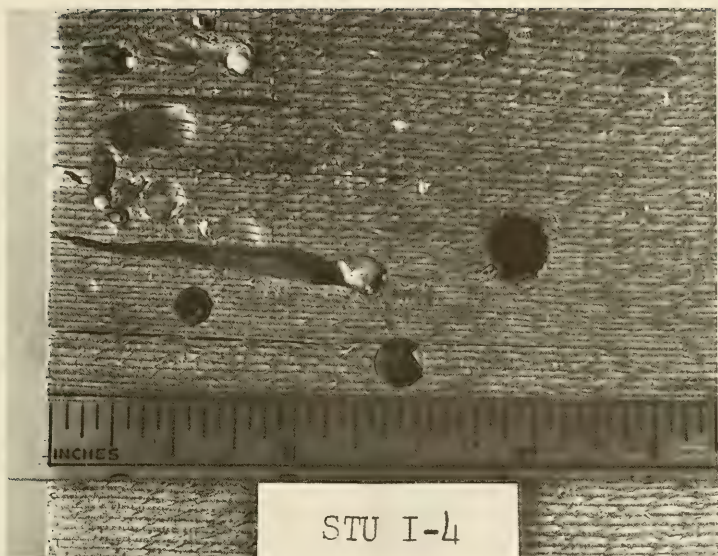


Figure 13. A borer that had penetrated about 1-1/2 inches into the wood.



Figure 14. Interior of wood completely riddled by borers. The shells of the molluscan borers are visible.



Figure 15. Amphipods, a shrimp-like crustacean, from a 6,800-foot depth.



Figure 16. Closeup view of *Xylophaga* sp.

Brownish fungi hyphae (without the fruiting bodies) were detected in the wood. An unsuccessful attempt was made in the laboratory to induce fructification by the fungi for classification purposes.

Rope Specimens. A heavy growth of slime bacteria was present over the surfaces of cotton and Manila ropes, and a light growth of slime was present over the surfaces of nylon and polypropylene ropes (Figure 17).

The fibers of cotton rope were decayed considerably by bacterial action, and as a result were easily pulled apart by tweezers (Figure 18). When the cotton rope was handled after it had been dried, the rope fibers crumbled into small pieces. Only a few borers were found on the surface of the cotton rope and none of these had bored into the rope.

The 1/2-inch-diameter Manila rope specimens were severely damaged by both borers and microorganisms. Borers ranging in size from 1/32-inch to 1/8-inch diameter had completely infested the entire length of the 5-foot-long rope specimens (Figure 19). The rope fibers were severed completely as the borers penetrated deep into the rope. The slime bacteria were responsible for the decay and deterioration of the fiber materials.

Examination of the nylon and polypropylene ropes under a stereoscopic microscope showed that the fibers of these ropes were neither severed nor damaged by marine borers. On the contrary, the fibers were in excellent condition (Figure 20). Table 9 compares the breaking strength of rope specimens before and after deep-sea exposure.

Plastic Specimens. The sections of 3-foot-long solid plastic rods and vinyl tubes recovered after 13 months on the sea floor in 6,800 feet of water are shown in Figure 21.

There were numerous deep and shallow borer holes present underneath the area where large wooden bait pieces were fitted over the lower and upper sections of the plastics (Figure 22). It was found that the lower section exposed about 0.5 foot above the sediment layer had more borer holes than on the upper sections exposed about 3 feet above the sediment. In other words, the borers were found to be more active near the sediment than 3 feet above the sediment layer.

The number and size of the borer holes found on the surface of the plastic specimens are presented in the Appendix.

A vinyl tube (NCEL No. 338) intended for low-temperature use had a heavy bacterial slime growth over the entire tube and over the plastic, rubber, and burlap wrappings. When recovered, the open tube was quite rigid and had decreased in diameter by about 1/8 inch, perhaps because the plasticizer or some other chemicals used in the tube's formulation may have been lost as a result of bacterial slime activity or other effects of the deep-sea environment. The other three vinyl tubes listed in the Appendix had a light slime growth over the surface; the diameters of these tubes remained unchanged except where marine borers had penetrated the surface of the plastic under the area of the wooden bait pieces.

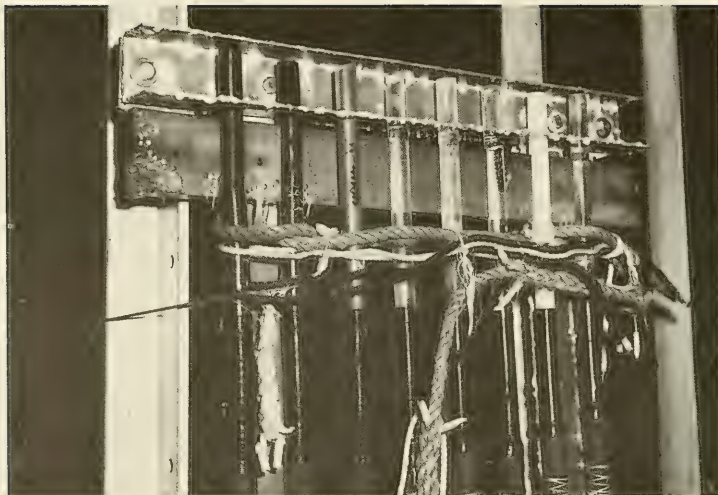


Figure 17. Rope specimens secured to bio-rack, immediately after recovery. Notice the dangling section of a cotton rope on the left. Photographed at night.



Figure 18. Cotton rope deteriorated by bacterial action.



Figure 19. Manila rope deteriorated by marine microorganisms and borers.



Figure 20. Nylon and polypropylene rope specimens, in excellent condition.

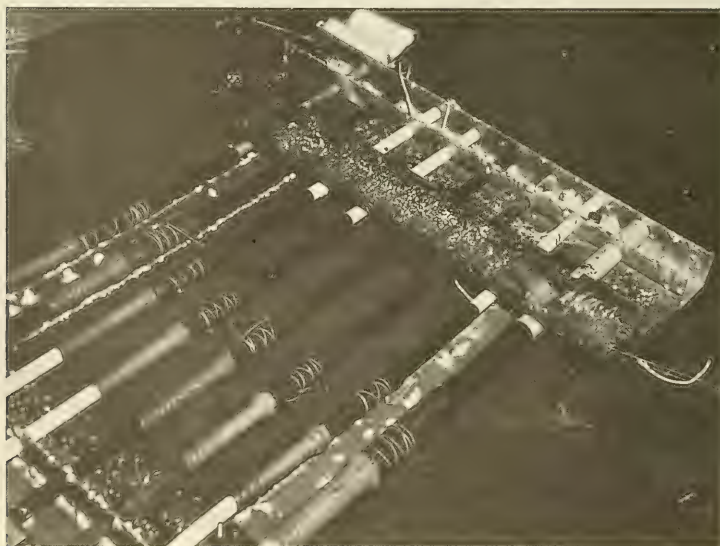
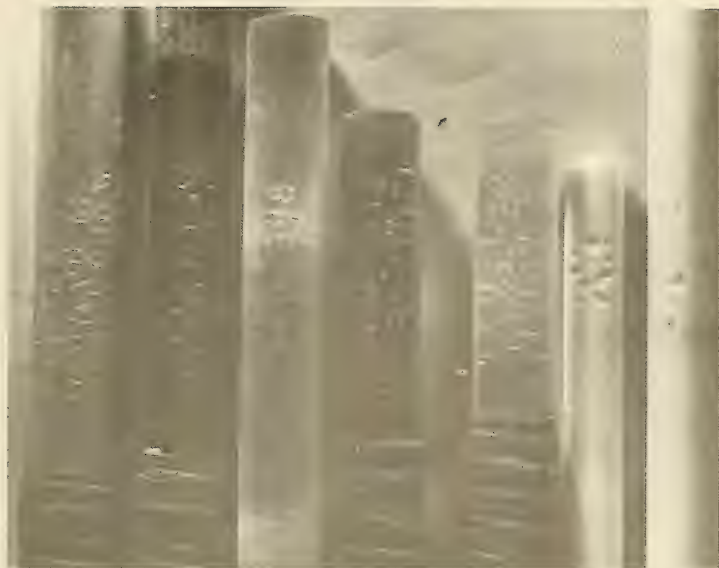
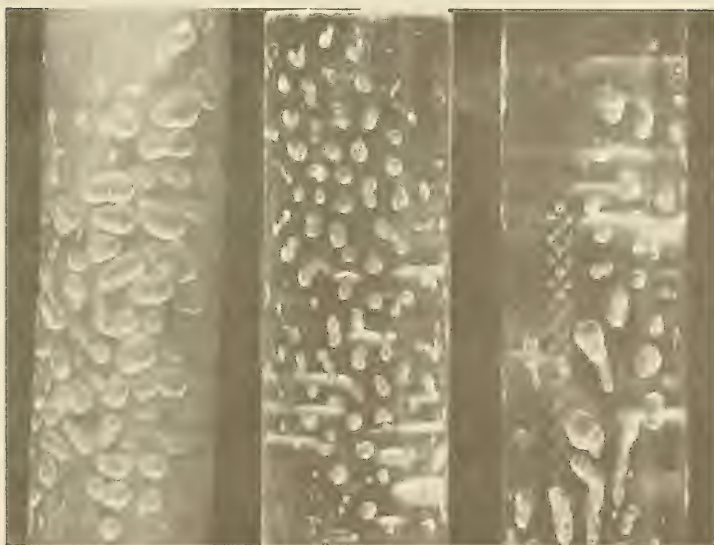


Figure 21. Plastic rods and tubes immediately after recovery. Borers are visible in bait piece.



(a) Partial view.



(b) Closeup view.

Figure 22. Numerous shallow and deep holes made by borers in plastic rods and tubes underneath the area of wooden bait piece.

Table 9. Breaking Strength of Rope Specimens Before and After Deep-Sea Exposure

Rope	Diameter (in.)	Breaking Strength (lb) ^{1/}	
		Before Exposure	After Exposure
Cotton	1/2	1,340	0 ²
Manila	1/2	2,068	0 ²
Nylon	1/4	1,900	1,930
Polypropylene	5/16	1,810	2,040

^{1/} Average of two specimens for each test.

^{2/} Estimated 100% of tensile strength of rope destroyed by microorganisms and borers.

Moisture absorption analysis was performed on the plastic rod and tube specimens. In order to determine the amount of moisture the plastics had absorbed during the deep-sea exposure, each of the 3-foot-long plastic specimens was weighed before being submerged. The figures for weight could not be used in the test because of the weight loss in the plastics as a result of marine borer attack.

For the moisture absorption study, a section about 3 inches long was cut from each of the 3-foot-long plastic specimens which were stored in plastic bags aboard ship; the section was then weighed in the laboratory. After being weighed, the test specimens were dried at room ambiency for 1 month and were then reweighed. The information about the amount of moisture gained by the plastic test specimens is presented in the Appendix.

Wrappings Around Plastics. Except for the tape wrapped around vinyl tube No. 338, the plastic electrical insulation tape (Figure 23), which was wrapped around the plastic rods and tubes, was attacked by marine borers. The small 1/32-inch-diameter holes were found along the edge of the overlap, but the borers did not penetrate the plastic tape. The deepest holes showed that some borers had penetrated approximately three quarters of the way through the 0.010-inch-thick electrical tape. It is believed that this is the deepest the borers are able to penetrate directly into the tape.

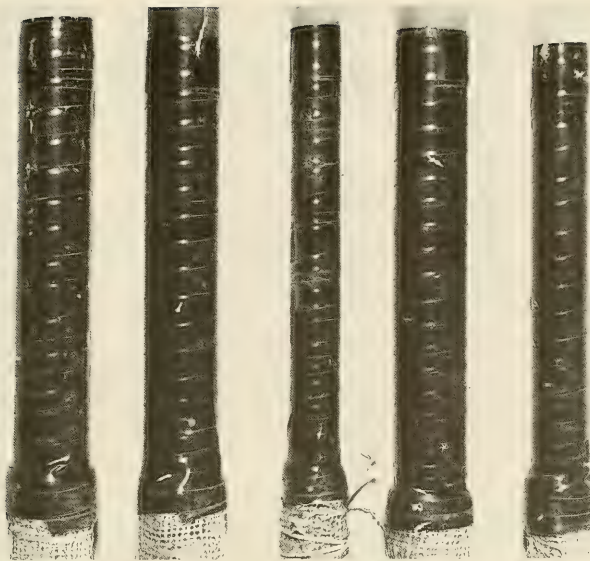


Figure 23. Plastic electrical insulation tape wrapped around plastic rods.

The burlap wrappings (Figure 24) on all the plastic rods and tubes were deteriorated by bacterial action, and the material could easily be torn apart by hand. The rubber electrical tape wrappings were not affected by fouling organisms although there were hydroids and sponges growing on the rubber material. Slight cracks (Figure 25) were found on the rubber and were probably produced by the effects of the deep-sea environment.

0.015-Inch Insulation on No. 16 Wire. The 15-inch-long nonstressed (straight) wire specimens were lost because the plastic cable clamps which held them to the phenolic laminated sheet were severed; however, the stressed (coiled) wire specimens were recovered (Figure 26). In the laboratory, the insulations were examined under a stereoscopic microscope for signs of any deterioration. Electrical tests, such as insulation resistance and voltage breakdown tests, were also conducted on these specimens. The results of the electrical tests are presented in Table 10.

The entire surface area of the silicone rubber insulation was roughened, and the thickness of the insulation was reduced considerably by the nibbling and chewing action of some marine organisms (Figure 27). The surfaces of other insulations, such as polyvinyl chloride, polyethylene, Government rubber styrene (GR-S), and neoprene rubber, were not affected. However, there were deep cracks in one area of a neoprene rubber insulation (Figure 28), exposing the conductor to seawater. The insulation was exposed about 3 feet above the sediment.

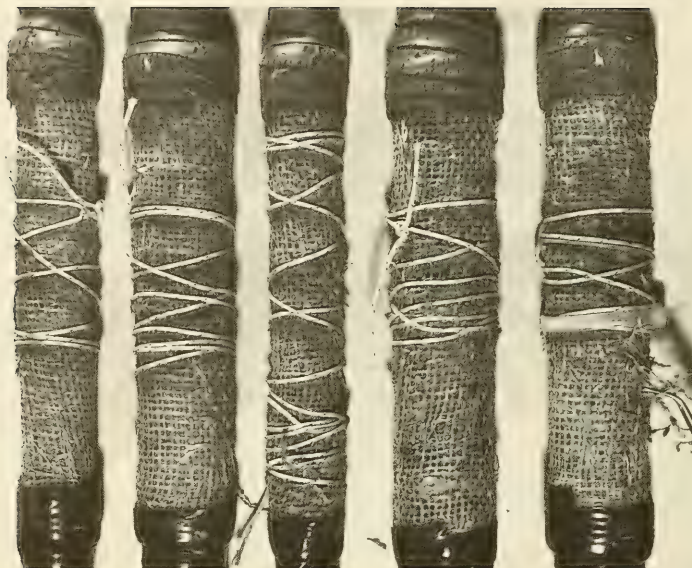


Figure 24. Burlap wrappings decayed by marine microorganisms.



Figure 25. Rubber electrical insulating tape over plastic rods.

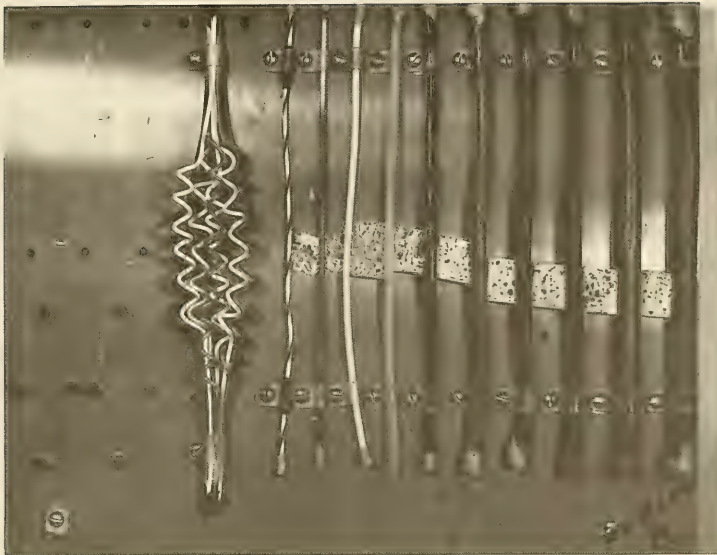


Figure 26. Coiled 0.015-inch insulation and single conductor and multiconductor electrical cables. Glass microscope slides are also attached to the phenolic sheet.



Figure 27. Silicone rubber insulation deteriorated by nibbling and biting action of some marine animals.

Table 10. Deep-Ocean Effects on Insulation Resistance of Electrical Insulating Materials

Insulating Material for Coiled Wires	Insulation Resistance (meg)		Voltage Breakdown ^{3/}
	Before Exposure ^{1/}	After Exposure ^{2/}	
Exposed Near Sediment			
Polyethylene	20,100,000	370,000	Did not fail
Polyvinyl chloride	4,400,000	480,000	Did not fail
Silicone rubber	6,200,000	60,400	Did not fail
Government rubber styrene (styrene butadiene rubber)	5,500,000	200,000	Did not fail
Neoprene	36,000	27,500	Did not fail
Exposed About 3 Feet Above Sediment			
Polyethylene	20,100,000	1,370,000	Did not fail
Polyvinyl chloride	4,400,000	800,000	Did not fail
Silicone rubber	6,200,000	32,000	Did not fail
Government rubber styrene (styrene butadiene rubber)	5,500,000	96,000 ^{4/}	One of two wires failed
Neoprene	36,000	32,000	Did not fail

^{1/} Average of eight tests.

^{2/} Average of two tests.

^{3/} Tested at 1,000 volts AC for 10 seconds.

^{4/} Average of one test. Insulation of one wire deteriorated.

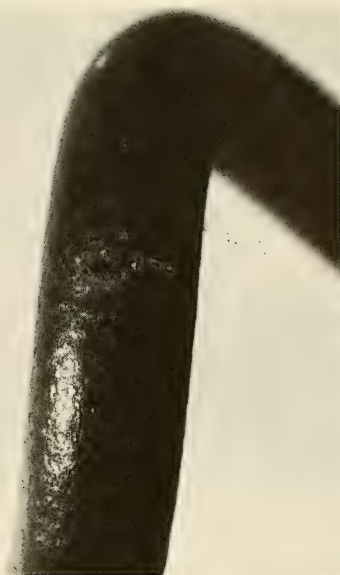


Figure 28. Deep cracks in neoprene rubber insulation. The wire was exposed to seawater.

Electrical Cable Insulation for Single Conductors and Multiconductors. The insulations of the 10-inch-long electrical cables (Figure 26) were examined under a stereoscopic microscope for signs of any biodeterioration and for any physical effects of the deep-sea environment.

Biodeterioration due to borer activity was more pronounced (especially in the area of a wooden bait piece) on a set of electrical cable insulations which were exposed about 0.5 foot above the sediment layer than on an identical set of insulations which were exposed about 3 to 4 feet above the sediment. The insulating materials which were damaged by the borers under a wooden bait piece were Teflon (Figure 29), polyvinyl chloride, silicone rubber, bakelite, polyethylene, nylon, and fluorinated ethylene propylene. The insulating materials which were neither affected by borer activity nor by the deep-sea environment were butyl rubber, neoprene rubber, and natural rubber.

In addition to damage by borer activity under the wooden bait piece, the surfaces of the silicone rubber insulations were damaged by the nibbling and biting action of some marine organisms. As a result of this type of damage over the entire surface area (except underneath the area of cable clamps), the thickness of the insulation was reduced considerably (Figure 30).



Figure 29. Borer holes on the surface of Teflon electrical insulation in an area under the wooden bait piece.



Figure 30. Surface of silicone rubber damaged by nibbling and biting action of some marine animals. The section where the cable clamp was located was not damaged.

Laminated Plastics. The 1 x 6 x 1/8-inch laminated plastic materials (Figure 31) which were exposed near the sediment and about 3 feet above the sediment were not damaged. Percent moisture absorbed by the plastics was determined by weighing each of the test specimens before and after exposure in the sea. The results are presented in the Appendix.

FINDINGS

1. There is considerable biological activity occurring in the sediment at Test Site I.
2. Marine fouling organisms such as bryozoa, tube worms, and glass sponges were found on rock samples collected in the vicinity of Test Site I in 6,000 feet of water.
3. Hydroids and sponges were found in small amounts on certain metal specimens and on all of the nonmetallic specimens. Typical fouling organisms such as bryozoa and barnacles were not found on these panels.
4. Marine microorganisms were responsible for the deterioration of cotton and Manila rope specimens, burlap (jute fibers), and possibly a vinyl plastic tube (NCEL No. 338).
5. Two species of marine borers were found in wood specimens and have been identified as Xylophaga washingtona Bartsch and Xylophaga duplicata Knudsen. The borers were responsible for the deterioration of the following materials: (1) pine, cedar, oak, maple, ash, and redwood, (2) plastic rods (area under the wooden bait pieces) such as delrin, nylon, polycarbonate, Teflon, cellulose acetate, polyethylene, acrylics, and polystyrene, (3) vinyl tubes, and (4) Manila rope.
6. Electrical cable insulation composed of silicone rubber was deteriorated by the nibbling and biting action of some marine animals.
7. The following materials in various forms and for various uses were not affected by marine organisms: rubber vacuum tubing; nylon nuts and bolts; nylon and polypropylene ropes; ethyl cellulose cable clamps; neoprene, butyl, and natural rubber electrical cable insulation; various plastic laminated sheets; and glass microscope slides.

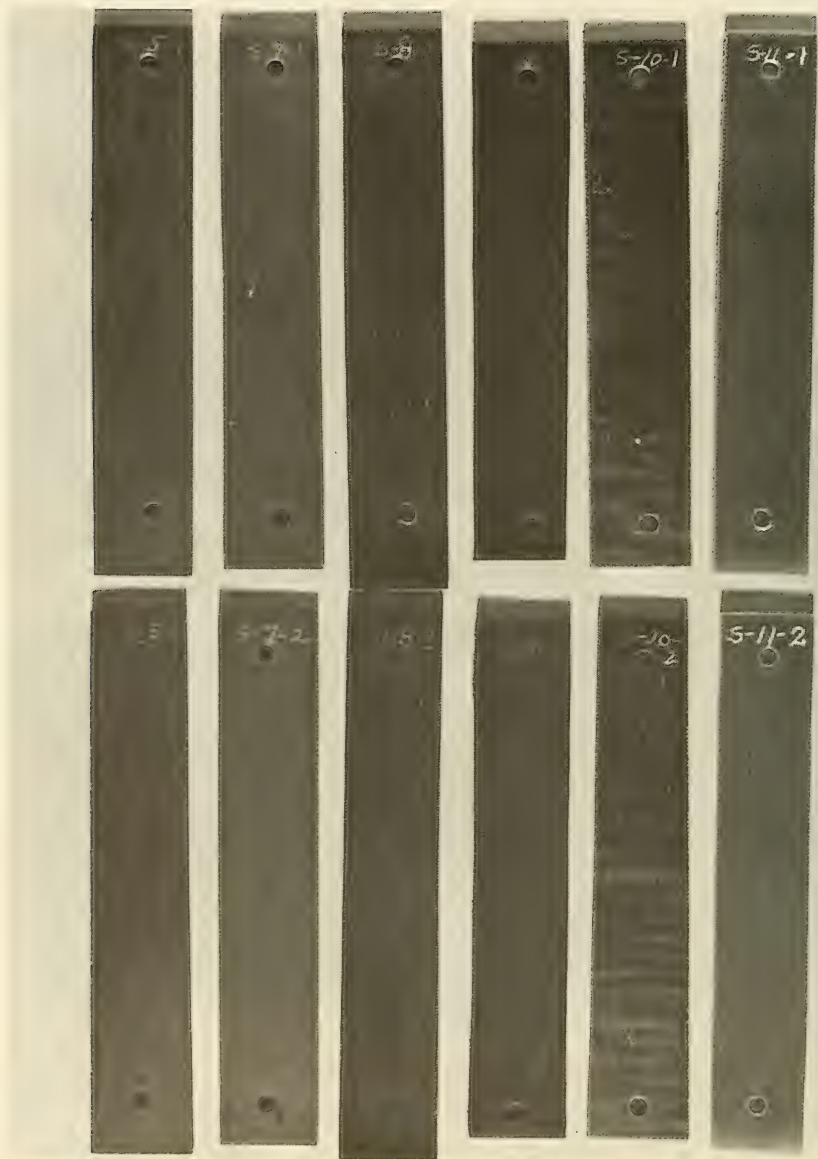


Figure 31. Laminated plastics after recovery from the sea.

CONCLUSIONS

1. The following materials are susceptible to total biological destruction and are not suitable for use in the deep ocean: untreated pine, fir, redwood, cedar, ash, oak, and maple; Manila and cotton ropes; and burlap (jute fibers).
2. The following materials are probably not susceptible to biological deterioration in the deep ocean: rubber vacuum tubing; acrylic sheet; nylon nuts and bolts; nylon and polypropylene rope; ethyl cellulose cable clamps; laminated plastic sheets; glass slides; and electrical cable insulations composed of neoprene, butyl rubber, natural rubber, and polyvinyl chloride.
3. The 3-foot-long plastic rods and tubes (except vinyl tube, NCEL No. 338), the polyvinyl chloride pipe, and the electrical cable insulations (except silicone rubber) may be suitable for use in the deep ocean if they are not placed in direct contact with wood.

FUTURE PLANS

The research program to determine the effects of the deep-sea environment on engineering materials is continuing.

A STU (I-2) which was exposed for a period of 2 years at a depth of 5,640 feet was recovered in October 1965. The materials aboard this STU are currently being examined, tested, and evaluated for biodeterioration.

Plans are being readied to retrieve STU II-2 in May 1966. It will have been exposed for 1 year on the sea floor at a depth of 2,400 feet.

ACKNOWLEDGMENTS

Dr. Ruth D. Turner, Museum of Comparative Zoology, Harvard University, identified the marine borer specimens. Dr. Jan Kohlmeyer, Institute of Fisheries Research, University of North Carolina, examined the wood specimens for fungi.

Appendix

BIOLOGICAL EFFECTS ON MATERIALS ASSEMBLED ON BIO-RACKS OF STU 1-4

Materials	NCEL No.	Size and Description	Summary of Results		Remarks
Plastic Rods		3-ft-long specimens commercially available through catalogs	Number and size of borer holes underneath wooden bolt piece exposed about 0.5 ft above sediment	Number and size of borer holes underneath wooden bolt piece exposed about 3 ft above sediment	Numerous holes were made on the surface of the majority of these plastic rods by marine borers. The holes were made on an area where large wooden bolt pieces were fitted at the upper and lower ends of each mortise into the plastic, and the holes were made on the plastic. Penetration into the plastic ceased when the wood was completely destroyed. Light hydroid growth was present on all the materials.
Delrin	339	3/4 in. diam	18 holes, 3/16 in. wide by 1/16 in. deep	5 shallow holes	Water absorption: 0.02%.
Nylon	340	3/4 in. diam	40 holes, 1/4 in. wide by 1/16 in. deep	2 holes, 3/16 in. wide by 1/32 in. deep	Water absorption: 1.70%.
Phenolic laminate	341	3/4 in. diam	None	None	There were 22 deep-sea sponges (1/4 in. long) attached to the surface of the plastic. Water absorption: 1.46%.
Polycarbonate	342	3/4 in. diam	15 holes, 1/8 in. wide by 1/32 in. deep	A single shallow hole	Water absorption: 0.20%.
Teflon	343	3/4 in. diam	10 holes, 3/16 in. wide by 1/16 in. deep	2 shallow holes	Water absorption: 0.00%.
Cellulose acetate	345	1 in. diam	50 holes, 3/16 in. wide by 1/16 in. deep	9 holes, 1/8 in. wide by 1/32 in. deep	Water absorption: 2.59%.
Polyethylene	346	1 in. diam	25 holes, 3/16 in. wide by 1/16 in. deep	20 holes, 3/16 in. wide by 1/32 in. deep	There were 10 sponges attached to the surface of the plastic. Water absorption: 0.03%.
Extruded acrylic	347	1 in. diam	100 holes, 1/8 in. wide by 1/32 in. deep	15 shallow holes	There were 5 sponges attached to the surface of the plastic. Water absorption: 0.35%.
Polystyrene	348	1 in. diam	100 holes, 1/8 in. wide by 1/32 in. deep	30 holes, 3/16 in. wide by 1/32 in. deep	There were 5 sponges attached to the surface of the plastic. Water absorption: 0.03%.
Cast acrylic	349	1 in. diam	30 holes, 1/8 in. wide by 1/32 in. deep	None	Water absorption: 0.40%.
Plastic Tubes		3 ft long, 1 in. OD, 1/8 in. wall thickness, commercially available	Exposed about 0.5 ft above sediment	Exposed about 3 ft above sediment	See remarks under Plastic Rods. A wooden dowling was placed inside each of the tubes to maintain rigidity. Only the ends of dowlings were attacked by borers.
Vinyl	338	Flexible, low-temperature tube, black	30 holes, 1/4 in. wide by 1/16 in. deep	2 holes, 1/8 in. wide by 1/16 in. deep	The entire tube was covered with heavy bacterial slime. The vinyl tube seems to contain chemicals preferred by microorganisms as a source of food. Outside diameter of the tube was reduced and the tube was quite rigid. After the tube was stored at ambient room temperature for about a month, the tube was covered with a heavy fungi growth. Water absorption: 0.62%.

Materials	NCEL No.	Size and Description	Summary of Results		Remarks
Vinyl	350	Flexible, fuel and lubricating tube, yellow	67 holes, 1/4 in. wide by 3/32 in. deep	6 holes, 1/4 in. wide by 1/16 in. deep	There were 15 sponges attached to this tube. Water absorption: 0.31%.
Vinyl	351	Flexible, general utility chemical hose, black	50 holes, 1/8 in. wide by 1/32 in. deep	4 holes, 1/8 in. wide by 1/16 in. deep	There were 20 sponges attached to this tube. Water absorption: 0.27%.
Vinyl	352	Semirigid, general utility chemical hose, black	25 holes, 1/8 in. wide by 1/64 in. deep	25 holes, 1/8 in. wide by 1/64 in. deep	There were 7 sponges attached to this tube. Water absorption: 0.02%.
Plastic Pipe	—	3 ft long, 1-5/16 in. OD, gray, unplasticized	10 holes, 1/16 in. wide by 1/64 in. deep	None	There were 5 sponges attached to the surface of the pipe. Water absorption: 0.26%.
Rubber Tubing	337	3 ft long, 5/8 in. OD, 3/16 in. wall thickness, 1/4-in.-diam. hole, red, and used as vacuum or pressure tubing	None	None	Remained in excellent condition. A 3 ft long, 1/8-in.-diameter stainless steel welding rod was inserted inside the tubing to maintain rigidity in bio-rock. Water absorption: 2.24%.
Electrical Cable Insulations		10-in.-long single conductor and multi-conductor cable. Ends sealed with silicone rubber cement	Exposed about 1 ft above sediment	Exposed about 3 ft above sediment	The wooden bait piece exposed near the sediment was severely damaged, and the bait piece exposed about 3 ft above the sediment was lightly damaged by borers.
Butyl jacket	353	0.508 in. OD, black	Excellent condition	—	No surface cracking, remained flexible. Slight etch mark caused by borer under wooden bait piece.
Butyl jacket	363	0.508 in. OD, black	—	Excellent condition	No change in physical condition.
Neoprene jacket	354	0.491 in. OD, black	Excellent condition	—	No change in physical condition.
Neoprene jacket	364	0.491 in. OD, black	—	Excellent condition	No change in physical condition.
Natural rubber	355	0.356 in. OD, black	Excellent condition	—	No change in physical condition.
Natural rubber	365	0.356 in. OD, black	—	Excellent condition	No change in physical condition.
Polyvinyl chloride	356	0.323 in. OD, black	About 15 shallow borer holes under wooden bait piece	—	Shallow scratch-like holes on the surface of insulation.
Polyvinyl chloride	366	0.323 in. OD, black	—	Excellent condition	Shallow scratch-like holes on the surface of insulation.
Silicone rubber	357	0.325 in. OD, blue	Surface deteriorated by nibbling and chewing by marine animals. Borer holes under wooden bait piece	—	The entire surface of the insulation (except area under cable clamp) is very irregular. The thickness of the insulation has been reduced considerably.
Silicone rubber	367	0.324 in. OD, blue	—	Few shallow borer holes present in area under wooden bait piece	The surface area of the insulation was roughened as a result of marine animals chewing and nibbling on the insulation.
Polyvinyl chloride, bore/lite	358	0.243 in. OD, black, 9033	Few shallow borer holes	—	Very shallow borer holes on the surface of insulation in an area under the bait piece.

Materials	NCEL No.	Size and Description	Summary of Results		Remarks
Polyvinyl chloride, bakelite	368	0.243 in. OD, black, 9033	—	Excellent condition	No change in physical characteristics.
Polyethylene	359	0.199 in. OD, low density, translucent	25 borer holes	—	Shallow borer holes under area of wooden bait piece. Other areas free of attack.
Polyethylene	369	0.199 in. OD, low density, translucent	—	1 shallow borer hole	Hole under wooden bait piece. Otherwise the material was in excellent condition.
Nylon	360	0.155 in. OD, white (opaque)	15 borer holes, the largest measured 1/8 in. wide by 1/32 in. deep	—	Holes under wooden bait piece. Otherwise the material was in good condition.
Nylon	370	0.155 in. OD, white (opaque)	—	5 shallow borer holes	Holes under wooden bait piece. Otherwise the material was in excellent condition.
Fluorinated ethylene propylene	361	0.120 in. OD, clear (transparent)	1 borer hole, 1/16 in. wide by 1/64 in. deep	—	Hole under wooden bait piece. Otherwise the material was in excellent condition.
Fluorinated ethylene propylene	371	0.120 in. OD, clear (transparent)	—	No borer hole	No change in physical characteristics.
Teflon	362	0.080 in. OD, white (opaque) with black stripes	1 borer hole, 1/32 in. wide	—	One shallow borer hole under wooden bait piece. Otherwise the material was in excellent condition.
Teflon	372	0.080 in. OD, white (opaque) with black stripes	—	10 shallow borer holes	Borer holes under wooden bait piece. Otherwise the material was in excellent condition. The wooden bait piece was severely riddled by borers.
Electrical Insulation		0.015-in.-thick insulation on No. 16 wire, 15 in. long	Exposed about 0.5 ft above sediment	Exposed about 3 ft above sediment	Results of insulation resistance and voltage breakdown tests are presented in Table 10.
Coiled Specimens (two of each specimen)					
Polyethylene	—	—	Not affected	Not affected	No visible deterioration.
Polyvinyl chloride	—	—	Not affected	Not affected	No visible deterioration.
Silicone rubber	—	—	Surface eroded	Surface eroded	The surface was deteriorated by nibbling and chewing action of marine animals.
Government rubber styrene (styrene butadiene rubber)	—	—	Not affected	Insulation was cracked on one of the wire specimens. Conductor was visible	Cracked due to unknown causes. No visible deterioration found on second wire specimen.
Neoprene rubber	—	—	Not affected	Not affected	No visible deterioration.
Straight Specimens			Lost	Lost	Plastic cable clamp was sheared.
Wooden Bait Piece					
Douglas Fir	—	Two 2 x 4 x 30-in. pieces bolted together	The wooden bait pieces were riddled by the borers. The majority of the borers in the wood were about 3/16 in. in diameter		The plastic rods and tubes were fitted inside the wood pieces so that a 4-in. area of the plastic materials was in contact with the wood. These wooden bait pieces were fitted over the lower and upper sections of the plastic rods and tubes.

Materials	NCEL No.	Size and Description	Summary of Results	Remarks
Wooden Panels		All 2 x 4 x 6-in. panels (total of 28 test panels)		The wooden panels exposed about 1 ft above the sediment experienced slightly heavier damage than those exposed about 4 ft above the sediment in the seawater environment.
Pine	—	43.9 gm before exposure	Moderate borer damage	Loss in weight of wood due to borer activity: 15%.
Fir	—	53.5 gm before exposure	Moderate borer damage	Loss in weight of wood due to borer activity: 12%.
Cedar	—	34.7 gm before exposure	Very heavy borer damage	Loss in weight of wood due to borer activity: 73%.
Ash	—	59.6 gm before exposure	Heavy borer damage	Loss in weight of wood due to borer activity: 50%.
Oak	—	62.6 gm before exposure	Heavy borer damage	Loss in weight of wood due to borer activity: 56%.
Redwood	—	39.6 gm before exposure	Very light borer damage	Loss in weight of wood due to borer activity: 2%.
Maple	—	64.0 gm before exposure	Heavy borer damage	Loss in weight of wood due to borer activity: 40%.
Ropes		4 to 5 ft, some with splices		Splices were placed in the rope specimens before exposure in the sea for performing breaking strength test when recovered.
Cotton	—	1/2 in. diam	Completely deteriorated by the activity of marine microorganisms	Breaking strength test could not be performed because of the rope's deteriorated condition.
Manila	—	1/2 in. diam	Completely deteriorated by the activity of marine microorganisms and borers. The borers were found deeply embedded inside the rope	Breaking strength test could not be performed because of the rope's deteriorated condition.
Nylon	—	1/4 in. diam	Not affected	See results of breaking strength test in Table 9.
Polypropylene	—	5/16 in. diam, black	Not affected	See results of breaking strength test in Table 9.
Wrapping Around Plastic Rods and Tubes				
Burlap (jute fiber)	—	—	Fibers deteriorated by marine microorganisms	Could be ripped apart by fingers.
Plastic insulation tape, electrical	—	Pressure-sensitive adhesive, 0.010 in. thick, 3/4 in. wide, black	Few shallow borer holes were found along the edge of the tape overlap	The borers had settled and started boring into the plastic tape in a protected area along the edge of the tape (overlap) where there probably was very little disturbance from water currents. Deep-sea sponges were attached to the tape.
Rubber insulation tape, electrical	—	3/4 in. wide, 0.027 in. thick, gray, spec. HH-7-111C	Slight amount of surface cracking from deep-sea exposure	Deep-sea sponges and hydroids were attached to the rubber tape.
Laminated Plastics		1/8 x 1 x 6 in.	Exposed about 1 ft above sediment	Several deep-sea sponges were growing on the surface of all the specimens. The specimens were placed in a plastic bag and sealed aboard ship in order to retain moisture.
			Exposed about 4 ft above sediment	

Materials	NCEL No.	Size and Description	Summary of Results		Remarks
Laminate	5-5-1	17,937 gm phenolic resin, fine weave, cotton fabric base; MIL-P-15035B; Type FBG	Not affected	—	Water absorption was 2.35%.
Laminate	5-5-2	18,075 gm	—	Not affected	Water absorption was 2.40%.
Laminate	5-7-1	18,156 gm phenolic resin, fine weave, paper base; MIL-P-3115B; Type PBE	Not affected	—	Water absorption was 1.95%.
Laminate	5-7-2	16,988 gm	—	Not affected	Water absorption was 1.93%.
Laminate	5-8-1	17,585 gm phenolic resin, cotton fabric base; MIL-P-15035B; Type FBG	Not affected	—	Water absorption was 2.61%.
Laminate	5-8-2	16,988 gm	—	Not affected	Water absorption was 2.68%.
Laminate	5-9-1	14,630 gm phenolic resin, nylon fabric base; MIL-P-15047B; Type NBG	Not affected	—	Water absorption was 1.24%.
Laminate	5-9-2	15,148 gm	—	Not affected	Water absorption was 1.45%.
Laminate	5-10-1	24,422 gm melamine resin, glass fabric base; MIL-P-15037B; Type GMG	Not affected	—	Water absorption was 0.19%.
Laminate	5-10-2	22,777 gm	—	Not affected	Water absorption was 0.20%.
Laminate	5-11-1	22,368 gm epoxy resin, glass fabric base; MIL-P-18177; Type GEE	Not affected	—	Water absorption was 0.19%.
Laminate	5-11-2	22,002 gm	—	Not affected	Water absorption was 0.21%.
Glass	—	—	Not affected	Not affected	No visible etching on the surface of glass.
Microscope Slide	—	—	Not affected	—	Could be reused.
Plastic Cable Clamp	—	1/16 x 3/8-in. clamps, various sizes; ethyl cellulose, yellow	Not affected	—	Could be reused.
Nylon Nuts and Bolts	—	1/4 x 1-in., black	Not affected	Not affected	Could be reused.

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